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Levels of toxaphene congeners in white whales (*Delphinapterus leucas*) from Svalbard, Norway

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Abstract

This study reports concentrations of three pesticide toxaphene congeners (CHBs; CHB-26, -50 and -62) from the blubber of ten adult, male white whales (*Delphinapterus leucas*) from Svalbard, Norway. The CHB congeners that occurred at the highest levels in the blubber of the white whales were, as expected, CHB-26 (4636 ± 1992 (SD) ng/g l.w.) and CHB-50 (6579 ± 2214 ng/g l.w.); CHB-62 (232 ± 231 ng/g l.w.) was also present, but at much lower concentrations. The mean level of the sum of the three CHBs (ΣCHBs = 11,447 ± 4208 ng/g l.w.) in this study is more than twice the mean concentrations of the well-known organochlorine (OC) pollutants ΣDDTs (sum of *pp′*-DDT, *pp′*-DDE, *pp′*-DDD) and ΣPCBs (sum of 27 PCB congeners) previously reported from the same individual white whales. The concentrations of CHBs in white whales from Svalbard are at the high end of the range for concentrations of these compounds compared to other Arctic white whale populations. Additionally, the contribution of CHBs to the overall OC burden is larger in white whales from Svalbard compared with their counterparts from other areas in the Arctic. Male white whales from Svalbard have several orders of magnitude higher concentrations of ΣCHBs compared to seals and polar bears (*Ursus maritimus*) from the same area. The high levels of CHBs in these whales, and their dominance in the OC pattern, suggests that white whales in Svalbard are exposed to high levels of this group of contaminants. Further studies are needed to investigate possible effects of CHBs and other OC contaminants on the white whale population in Svalbard.

Keywords: White whales; Beluga; Organochlorine pollutants; Toxaphene; CHB; Barents Sea; Marine mammals; Svalbard

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1. Introduction

Toxaphene is a term used to refer to a complex mixture of chemicals that consist primarily of chlorinated bornanes (CHBs), that was used widely as a pesticide in the USA, as well as in other parts of the world, prior to it being banned in the early 1980's because of its environmental persistence and toxicity (Saleh, 1991). The estimated global usage of CHBs is 1.33 million tons, with usage in the USA accounting for more than 40% of this amount (Voldner and Li, 1993, 1995; Li et al., 2001). Thus, it has been one of the most heavily used pesticides in the world (Li, 2001). Although this substance is no longer manufactured or used in the USA, CHBs and similar products are still used in Central and South America, Africa, Eastern Europe, the Indian subcontinent and in regions of the former Soviet Union (Voldner and Li, 1993; de March et al., 1998; de Geus et al., 1999). This pesticide has never been used in Norway (Voldner and Li, 1993; Fjeld et al., 2001).

CHBs are a concern with respect to arctic marine environments because they are highly persistent, lipophilic and toxic. CHBs bioaccumulate in lipid-rich tissues of marine organisms and biomagnify in marine food chains. They are transported via the atmosphere as well as ocean currents, which has resulted in a global distribution of these contaminants (Saleh, 1991). CHBs are found in the Arctic in relatively high concentrations in air and in seawater. They are also among the most dominant organochlorine (OC) pollutants in zooplankton, fish, and especially marine mammals compared to other OC pollutants such at PCBs and DDTs (de March et al., 1998; Muir et al., 1999). Even though the CHBs are a major OC contaminant in the Arctic, there is a lack of data regarding levels in air, water, sediment and in biota, especially from the European Arctic. Furthermore, there are no data on the long-term biological effects of CHBs in wildlife species (de March et al., 1998). Laboratory experiments on rodents have shown that these contaminants have neurotoxic, nephrotoxic and carcinogenic properties (de March et al., 1998; de Geus et al., 1999). *In vitro* studies suggest that they also cause endocrine disruption and have carcinogenic and genotoxic properties (de Geus et al., 1999).

Because CHBs biomagnify in marine food chains, there is cause for concern regarding exposure effects of these compounds on apex predators in arctic marine ecosystems. Previous investigations on white whales (*Delphinapterus leucas*) from Svalbard reported relatively high levels of well-known OC chemicals such as PCBs and DDTs (Andersen et al., 2001). The levels of these contaminants were similar to or higher than levels reported from white whales in the North American Arctic. A study of polybrominated diphenyl ethers (PBDEs) in Svalbard white whales showed that the levels of these compounds in Svalbard are also high compared to Arctic Canada, but still low when compared to levels in marine mammals from lower latitudes (Wolkers et al., 2004a). CHBs are usually among the most dominant OC contaminants, together with PCBs and DDTs, in studies of white whale stocks from Canada and Alaska (Muir et al., 1999). Information on the levels of CHBs in white whales from Svalbard is lacking. The objectives of this study were to 1) investigate the levels of CHBs in white whales from Svalbard, 2) evaluate their importance relative to other OC groups previously reported in Andersen et al. (2001) and 3) compare the results from this study with other white whale populations and marine mammal species from the Barents Sea area.

2. Methods

2.1. Sampling

Ten adult male white whales were live-captured between 7 July and 12 August 1995–1997 in Van Mijenfjorden (77°45′N, 15°00′E) and Van Keulenfjorden (77°35′N, 15°00′E), on the west coast of Spitsbergen, Svalbard, Norway. White whales are a protected species in Svalbard and hence are not hunted by local people. Thus, blubber was sampled from live-captured animals. The Norwegian Animal Research Authority and the Governor of Svalbard approved all capture and sampling procedures. The whales were captured using a net set from shore. Standard length was measured to the nearest 5 cm and sex was determined by examining the external genitalia. Based on skin colour and body size all 10 animals were classified as adults.

Four to 10 biopsies of skin and blubber were sampled from each animal from an area just anterior

to the dorsal ridge. The tissue samples were then tightly wrapped in aluminium foil and kept frozen at −20 °C until analysis. All biopsies included the epidermis, dermis and various lengths of the hypodermic blubber column depending on the blubber coring method that was used over the years of sampling. Only the blubber tissue was used in analyses of OCs. The variations in the lengths of the blubber biopsies caused the lipid content to vary (0.75–96%; Andersen et al., 2001). The samples with low lipid contents contained more connective tissue than blubber; these samples originated from biopsies that included only the outermost part of the blubber column. More details on capturing methods, sampling procedures and sample preparation can be found in Andersen et al. (2001).

2.2. Determination of CHBs

The determinations of the toxaphene congeners CHB-26 (2-exo, 3-endo, 5-exo, 6-endo, 8b, 8c, 10a, 10b-Octachlorobornane), CHB-50 (2-exo, 3-endo, 5-exo, 6-endo, 8b, 8c, 9c, 10a, 10b-Nonachlorobornane) and CHB-62 (2,2,5,5, 8b, 8c, 9c, 10a, 10b-Nonachlorobornane) were performed at the Laboratory of Environmental Toxicology, Norwegian School of Veterinary Science, Oslo, Norway. The basic methods used for extraction and sample clean-up are described in Brevik (1978) and Bernhoft and Skaare (1994), but modifications described in Andersen et al. (2001) were also used in this study. The results of other OC pollutants in the same samples were reported in Andersen et al. (2001).

Briefly, the methods followed were that several biopsies from each whale were pooled, macerated, frozen and homogenised (Ike Ultra Turrax™, Janke and Kunkel, Gmbh and Co., KG, Germany). Small (known weight) samples (approximately 0.2–1 g) of blubber were added to 10 ml of water and homogenised in a mixture of acetone and cyclohexane (1:2) with an ultrasonic homogeniser (4710 Series, Cole Parmer Instruments Co., Chicago, IL, USA). Lipid extraction with solvents was repeated three times. The final volume of the extracts was adjusted to 5 or 10 ml, depending on the size of the sample. The extractable lipid content in each sample was determined gravimetrically in 2 ml of the extract. Lipids were removed from the remaining extracts with ultra clean sulphuric acid, H_2SO_4. After centrifuging, the remaining organic phase was evaporated in a three step process using a careful stream of N_2-gas. The extracts were then used in the analyses of CHBs in this study.

Each extract was separated into two fractions on a silica column. Both fractions were analysed on a gas-chromatograph (GC-ECD). The basic separation techniques for the CHB congeners are described in de Boer and Wester (1993); this study also used the modifications described in Føreid et al. (2000). The analytical separation of the CHB congeners was performed on a Hewlett Packard (HP) gas-chromatograph (GC) (Hewlett Packard, Pao Alto, CA USA) coupled to a ^{63}Ni electron-capture detector (ECD), equipped with an HP 7683 Auto Sampler. The samples were analysed on an SPB-5 fused silica capillary column (60 m, 0.25 mm i.d., 0.25 μm film; Supelco, Bellefonte, PA, USA). The injector temperature was 210 °C and 2 μl of sample was injected, in pulsed splitless mode, with a pulse pressure of 60 psi for 1 min. Helium was used as the carrier gas and separation was performed at a constant flow of 1.5 ml min^{-1}. The column temperature was initially 90 °C for 3 min, and then it was raised 35 °C min^{-1} to 200 °C. This temperature was held for 53 min, and then it was again raised at a rate of 3 °C min^{-1} to 220 °C, which was held for 8 min. The temperature was then raised at a rate of 5 °C min^{-1} to 275 °C, which was held for 15 min. The detector temperature was 300 °C. The individual CHBs were determined by comparison with corresponding components in a standard mixture of CHB-26, -50 and -62, obtained from Promochem GmbH (Wesel, Germany). In addition, the results were verified on a GC coupled to a HP 5973 quadrupole mass spectrometer (MS) operating in selected ion monitoring (SIM) mode on negative chemical ionisation (NCI). Methane was used as the reagent gas. The temperature was 106, 150, 280 °C for the quadrupole, the ion source and the interface, respectively. The following ions were selected: internal standard (PCB-112): m/z 323.9, 325.9 and 327.9, CHB-26: m/z 347.8, 376.9 and 378.9 CHB-50: m/z 410.9, 412.9 and 414.8, CHB-62: m/z 374.9, 376.8 and 379.0. The GC conditions were the same as for the GC-ECD.

Table 1
Concentration of CHBs (ng/g l.w.), presented as individual CHB congeners and ΣCHBs (the sum of CHB-26, -50 and -62), in blubber biopsies of 10 male white whales from Svalbard

CHB congener	Median	Min.–max.	Mean ± S.D.
CHB-26	5109	1996–7700	4636 ± 1992
CHB-50	6403	2954–9796	6579 ± 2214
CHB-62	149	84–850	232 ± 231
ΣCHB	11,638	5034–16,338	11,447 ± 4208

2.3. Analytical quality

The Laboratory of Environmental Toxicology was accredited in 1996 as a testing laboratory according to the requirements of NS-EN ISO/IEC 17025. The laboratory's analytical performance with respect to the studied compounds was confirmed during inter-calibration tests organised by Quasimeme. For this study, the relevant Quasimeme test was Round 18, DE-2. The test results for CHB-26, -50 and -62 were within the acceptable range ($z<2$) in each of three different biological samples analysed (assigned error was 12.52–12.83%).

Quality assurance procedures in this study included the use of blanks and spiked samples. The recovery percentages were 98 ± 9% for CHB-26, 88 ± 7% for CHB-50 and 106 ± 7% for CHB-62, respectively. No peaks were observed in the blank samples. Detection limits were defined as three times the background noise. The detection limit ranged from 2 to 25 ng/g w.w. In four of the whales CHB-62 was below the detection limit; a value of half the detection limit was assigned. Since the lipid content of the blubber biopsies varied a great deal, from 0.75% to 96% (Andersen et al., 2001), the CHB results were expressed on a lipid weight basis. All quantifications were carried out within the linear range of the ECD-detector, using a 7-levels standard curve.

2.4. Statistics

Statistical analyses were performed using SPSS (Version 7.0 for Windows 95, Inc., Ill., USA). Non-parametric Spearman rank correlation (r_s) was used to test the relationship between whale length and levels of the sum of CHB-26, -50 and -62 (ΣCHBs). The significance level was set to $p<0.05$ and 2-tailed p-values are presented. Numerical values are presented as arithmetic means ± standard deviation (S.D.) in the text, and in addition as medians with maximum and minimum values in Table 1. Although, median values are probably the best measure of central tendency for data that are not normally distributed (Norman and Streiner, 1994), mean ± S.D were also calculated and presented in order to permit comparisons with other studies.

3. Results

The individual concentrations of CHB-26, CHB-50, and CHB-62 and ΣCHBs are presented in Table 1. A chromatogram from the GC-analyses of blubber extracts from one whale is depicted in Fig. 1, where the peaks of CHB-26, -50 and -62 are indicated.

CHB-26 and CHB-50 were the two dominant CHB congeners, contributing 40 ± 4.6% and 58 ± 4.3%, respectively, to mean ΣCHB. CHB-62 occurred at much lower levels, representing only 1.9 ± 1.2% of the mean ΣCHBs.

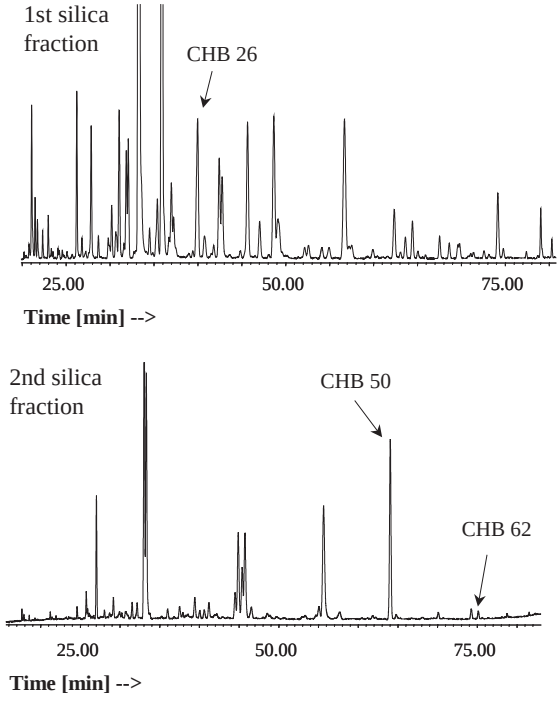

Fig. 1. Chromatogram of the GC-analyses of CHBs in blubber of one of the sampled white whales from Svalbard. The arrows indicate the analysed congeners CHB-26, CHB-50 and CHB-62.

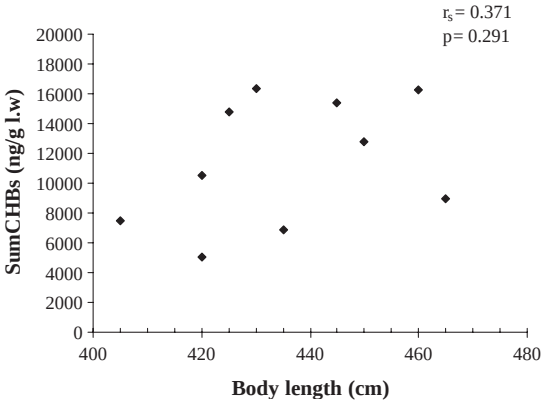

Fig. 2. Body length as a function of ΣCHBs (the sum of CHB-26, -50 and -62) in 10 white whale males from Svalbard. r_s = Spearman's rank correlation coefficient. p-values are 2-tailed.

There was a lot of variation in CHB concentrations among the 10 white whales sampled, both for the individual congeners and for ΣCHBs (Table 1, Fig. 2). There was no correlation between body length and concentrations of ΣCHBs (Fig. 2; $|r_s| < 0.5$, $n = 10$, $p > 0.10$) in the whales.

4. Discussion

4.1. Relationship between CHB levels and length

There was no significant relationship between whale length and levels of ΣCHBs in this study. This was not unexpected given that other OC accumulation patterns studied in white whales have not been age-dependent (Stern et al., 1994; Muir et al., 1996a,b; Andersen et al., 2001). Although, in other cetacean and seal species, males generally accumulate increasing levels of OC contaminants with increasing age (Norstrom and Muir, 1994; Tanabe et al., 1994; Aguilar et al., 1999). Additionally, it should also be noted that all of the whales sampled in this study were fully adult males, so the relatively small differences in their length may not be related to age.

4.2. Interspecies differences of CHB levels

Levels of CHBs in marine mammals from Svalbard and the Barents Sea are presented in Table 2. CHB levels in white whales from this area are: 700× higher than in ringed seals (*Phoca hispida*); ~200× higher than polar bears; ~100× higher than harbour seals (*Phoca vitulina*); ~25× higher than in harp seals (*P. groenlandica*); ~5× higher than in minke whales (*Balaenoptera acutorostrata*) and; 10–100 times the levels found in cod (*Gadus morhua*) from the Barents Sea (Karlsson et al., 1997; Føreid et al., 2000; Wolkers et al., 1998, 2000, 2004b; Frydenlund and Øvervoll, 2002). White whales have the highest CHB concentrations thus far reported from any marine species investigated in Svalbard and the broader Barents Sea area.

Interspecies differences in OC levels, such as those shown in Table 2, can be explained by factors such as diet, age, trophic level, feeding areas, nutritional and reproductive status, sex, and species–specific capabilities regarding metabolic breakdown and excretion of contaminants. Polar bears in the Barents Sea area feed almost exclusively on seals (Derocher et al., 2002) and are thus higher in the marine food chain than white whales. However, polar bears are known to have better metabolic and excretion abilities with respect to OCs compared to cetaceans, partly due to their more recent terrestrial ancestry (Tanabe et al., 1988; Norstrom et al., 1992; Norstrom and Muir, 1994; Skaare, 1995). Cetaceans have been found to have a lower OC metabolising ability compared to seals as well (Tanabe et al., 1988; Norstrom et al., 1992; Murk et al., 1994), although ringed, harbour and harp seals feed at a similar trophic level to white whales (Dahl et al., 2000; Wathne et al., 2000; Andersen et al., 2004). Even though an in vitro study has showed that CHB-26 and -50 are equally resistant to metabolic degradation in all seal and whale species examined (Boon et al., 1998), several other studies have suggested that white whales have lower capacities to metabolise pollutants relative to seals and polar bears. This might explain the higher levels of CHBs found in this species, including CHB-26 and -50 (Norstrom and Muir, 1994; Wolkers et al., 1998, 2000, 2004b).

4.3. Spatial trends of CHB levels

Levels of CHBs in male white whales from Svalbard are in the same order of magnitude as levels in male white whales from the St Lawrence Estuary in Canada (Gouteux et al., 2003), and male white whales from Cumberland Sound, Southeast Baffin Island and

Table 2
Mean levels (ng/g l.w.) ± S.D. of three CHB congeners and Total CHBs in blubber of male white whales, male ringed seals, male harbour seals, male harp seals, minke whale and male polar bears from the Svalbard and Barents Sea area

Species	Sampling year, period	Age (years)	CHB-26	CHB-50	CHB-62	Total CHBs
White whales[a] Svalbard ($n=10$)	Summer/fall 1995–1997	Adults	4636 ± 1992	6579 ± 2214	232 ± 231	11,447 ± 4208
Ringed seals[b] Svalbard (west) ($n=5$)	Spring 1993	1–17	2.6 ± 1.1	4.9 ± 2.4	1.8 ± 1.1	9.2 ± 4.3
Ringed seals[c] Svalbard (west) ($n=7$)	Spring 1996	Adults	7.7 ± 4.2	9.0 ± 5.4	n.a.	51.0
Harbour seals[d] Svalbard (west) ($n=6$)	June 2000	Adults	59.7 (43.4–82.2)	88.5 (62.7–124.8)	n.a.	170.7 (121.9–238.8)
Harp seals[e] Barents Sea NW ($n=13$)	August 1997	≤4	75 (63–89)	90 (76–107)	16.3 (14–19)	496 (418–587)
Minke whales[f] Barents Sea ($n=15$)	May–June 1998	n.a	980	820	740	2540
Polar bears[b] Svalbard ($n=6$)	Spring/summer 1992–1993	>5	17 ± 26	27 ± 46	4.1 ± 6.2	48 ± 77

n = sample size.
n.a. = not available.
[a] Results from the current study; Total CHBs = ΣCHBs = CHB-26 + CHB-50 + CHB-62.
[b] Results from Føreid et al. 2000. Similar analytical methods and laboratory as in this study were employed. Total CHBs = CHB-26 + CHB-50 + CHB-62.
[c] Results from Wolkers et al. 1998; Level of CHB-62 was not available in this study. Total CHBs (Total toxaphene in Wolkers et al., 1998) is calculated using a multiplication factor based on the total surface area from all toxaphenes relative to CHB-26 and -50.
[d] Results from Wolkers et al. 2004b (concentration given as geometric mean with 95% confidence interval in brackets). Total CHBs is the geometric mean of the sum of CHB-26, -40, -44 and -50. Level of CHB-62 was not available in this study.
[e] Results from Wolkers et al. 2000; concentration given as geometric mean with 95% confidence interval in brackets. Total CHBs (ΣPCC in Wolkers et al. 2000) is calculated as 3 X the sum of CHB-26 and -50. Sex of sampled animals was not available.
[f] Results from a draft report from Frydenlund and Øvervoll 2002. Pooled samples of 15 minke whales (sex of the animals are unknown). Standard deviation was not available.

Hudson Bay in Arctic Canada (Muir et al., 1999). This is contrary to levels of PCBs and DDTs that are an order of magnitude higher in the St Lawrence animals compared with white whales from Svalbard and the Canadian Arctic (Muir et al., 1990, 1996a; Andersen et al., 2001). Gouteux et al. (2003) suggested that atmospheric transport of CHBs might be the most important input to both the Canadian Arctic and the St Lawrence Estuary based on the similar levels of CHBs in these two distinct environments. CHB concentrations in white whales from Svalbard are 2–3 times higher than in white whales from West-Greenland, Jones Sound and the South Beaufort Sea (Canadian Arctic) and Alaskan stocks (Fig. 3) (Muir et al., 1990; Muir, 1994, 1996; Stern et al., 1994; Becker et al., 1995, 1997; de March et al., 1998; Krahn et al., 1999), which suggests that there are either local sources for CHBs in Svalbard or that specific air or ocean currents carry more CHBs to the Svalbard Archipelago compared to areas further to the west at similar latitudes. The Northeast Atlantic, which includes Svalbard, might receive CHBs via aerial transport from the American continent as well as from the European continent (de Boer and Wester, 1993; Oehme et al., 1996). Air temperature might also play a role in the transport of CHBs, determining in part when and where they will be deposited; Svalbard is Gulf Stream warmed, particularly on the west coast, so cooling of air masses might occur further to the north than on the Canadian side of the North Atlantic.

There are many factors that can complicate geographical comparisons of OC levels in marine mammals that are based on different studies; variation in biological parameters of the sampled animals, differences in collection year and season, and inconsistencies in sampling (see Andersen et al., 2001) and analytical methods. Fig. 3 presents CHB results only from male white whales, so variation due to gender is controlled for (Tanabe et al., 1994; Aguilar et al., 1999), but the data from different areas do still have dissimilarities. CHB levels in this study were lipid normalised and therefore expressed on a per gram

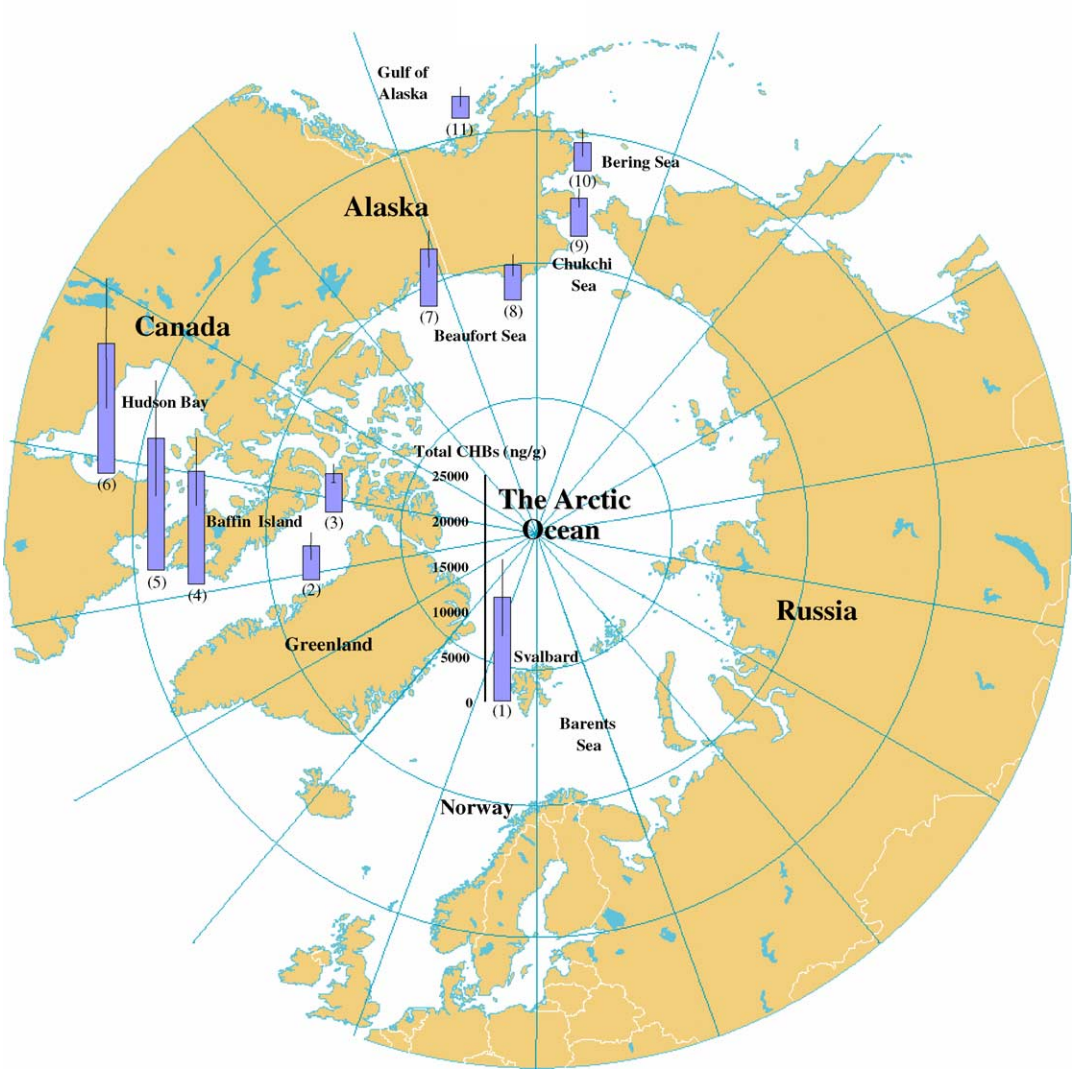

Fig. 3. Mean concentration (ng/g) ± SD of Total CHBs in the blubber of male white whales from various arctic stocks. CHB results from this study are determined using a congener-specific method based on analyses of three congeners; CHB-26, -50 and -62. Total CHB, or ΣCHBs, reported in this study is the sum of these three congeners. Total CHBs in the other white whale stocks is calculated by summing up the area of 19 or 20 peaks in the chromatogram using technical toxaphene as a standard. The Total CHB levels from all the stocks are presented on a wet weight basis, except the levels of ΣCHBs in the Svalbard stock, which are presented on a lipid weight basis. Data are compiled from: (1) Svalbard: current study, (2) W. Greenland: Stern et al. (1994), (3) Jones Sound: Muir et al. (1990), (4) Cumberland Sound, (5) S.E. Baffin Island and (6) S. Hudson Bay: Muir et al. (1999), (7) S. Beaufort Sea: Muir (1994, 1996); de March et al. (1998), (8) E. Beaufort Sea: Muir et al. (1990), (9) E. Chukchi Sea, (10) E. Bering Sea and (11) Cook Inlet: Becker et al. (1995, 1997); Krahn et al. (1999).

lipid basis, while CHB levels from other areas presented in Fig. 3 were expressed on a wet weight basis (74–95% lipids; Muir et al., 1990, 1999; Muir, 1994, 1996; Stern et al., 1994; Becker et al., 1995, 1997; de March et al., 1998; Krahn et al., 1999). Thus, the Svalbard results might be slightly upwardly biased on this basis. Another factor that complicates this geographical comparison is the dissimilar number of congeners included in total CHB levels. Total CHB levels from this study are the sum of three congeners (ΣCHBs = CHB-26, -50 and -62), whereas in the other studies displayed in Fig. 3 the CHB level is the sum of

19–20 CHB congeners. Although CHB-26 and -50, reported in this study, are normally among the most abundant CHB congeners found in marine mammal samples (Stern et al., 1992; Muir et al., 1999; Vetter and Oehme, 2000), the small number of congeners reported in this study undoubtedly biases the Svalbard results downwards to some extent.

There are real biological factors that also influence geographical patterns in OC levels in marine mammals such as diet. Populations of the same species can prefer prey at different trophic levels in different areas which can influence OC levels (Norstrom and Muir, 2000). However, there is no reason to believe that male white whales from Svalbard feed at a different trophic level compared to their counterparts from other areas in the Arctic. Based on fatty acid analysis of the blubber, the white whales from Svalbard eat polar cod (*Boreogadus saida*), capelin (*Mallotus villosus*) and shrimp, similar to white whales in other regions (Dahl et al., 2000).

The mean level of ΣCHBs found in this study is about 2.5 times higher than the mean levels of ΣDDTs (sum of *pp′*-DDT, *pp′*-DDE, *pp′*-DDD) and ΣPCBs (sum of 27 PCB congeners) and about 4.5 times higher than the mean level of ΣCHLs (sum of heptachlor epoxide, oxychlordane, *cis*-chlordane, *trans*-nonachlor, and *cis*-nonachlor) reported in the same individual male white whales by Andersen et al. (2001). In Canadian and Alaskan white whale stocks the levels of CHBs were equal to or somewhat higher (up to 1.5 fold) than the PCB concentrations (Muir et al., 1990; Becker et al., 1995, 1997; Krahn et al., 1999). In Greenlandic white whale stocks, the levels of CHBs are lower than both PCBs and DDTs (Stern et al., 1994). The geographical differences in OC patterns in white stocks can be summed up as follows: Svalbard, CHBs ≫ PCBs = DDTs > CHLs; Greenland: PCBs > DDTs > CHBs > CHLs; Canadian Arctic and Alaska, CHBs ≥ PCBs > DDTs > CHLs.

CHBs have been used less in Western Europe than on the American Continent (de Boer and Wester, 1993; Voldner and Li, 1993). It would therefore be reasonable to expect that levels of CHBs in the European Arctic would be lower than those in the North American Arctic (Muir et al., 1992; Zhu and Nordstrom, 1993; Wolkers et al., 1998, 2000; Føreid et al., 2000). However, white whales from Svalbard have a similar or slightly higher levels of CHBs compared to their counterparts from the North American Arctic and their OC pattern was more dominated by CHBs. CHBs were also found to be the most dominant OC group in a study of harp seals from the north-western parts of the Barents Sea, east of Svalbard, contrary to what has been found in previous studies of seals from other areas, including parts of Svalbard (Muir et al., 1992; Zhu and Nordstrom, 1993; Wolkers et al., 1998, 2000). The harp seals from the NW Barents Sea also had levels of CHB congeners CHB-26 and -50 that were 20-times higher than in seal species from the west-coast of Svalbard, and four times higher than in seals from the Canadian Arctic (Wolkers et al., 1998, 2000). Wolkers et al. (2000) suggested that the Barents Sea may be influenced by a local source of CHBs, in addition to atmospheric transport, resulting in higher CHB levels in this area. Satellite tracking of white whales from the west-coast of Svalbard has shown that they move frequently between this area and the east-coast including the north-western parts of the Barents Sea (Lydersen et al., 2001). If harp seals are exposed to a regional or local source, the situation would be similar for white whales in this area. However, the lack of data on CHBs in seawater from West Spitsbergen, the Barents Sea, and Norwegian and Russian coastal currents creates uncertainties about the input fluxes (de March et al., 1998). Based on the limited knowledge of CHBs in the European Arctic, it is not possible to suggest possible sources or transport mechanisms to the Barents Sea area. Hence, more studies on CHB levels in the air, marine sediments and sea water are necessary to say more about possible sources of CHBs to this area.

In conclusion, this study has shown that white whales from Svalbard accumulate high levels of CHBs that dominate their OC patterns. We recommend further studies to investigate possible effects of CHBs and other OC contaminants on the white whale population in Svalbard. Also, more extensive studies of CHBs should be performed in the Barents Sea ecosystem, including levels in the biota. Metabolism and food chain transfer studies would also be enlightening.

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